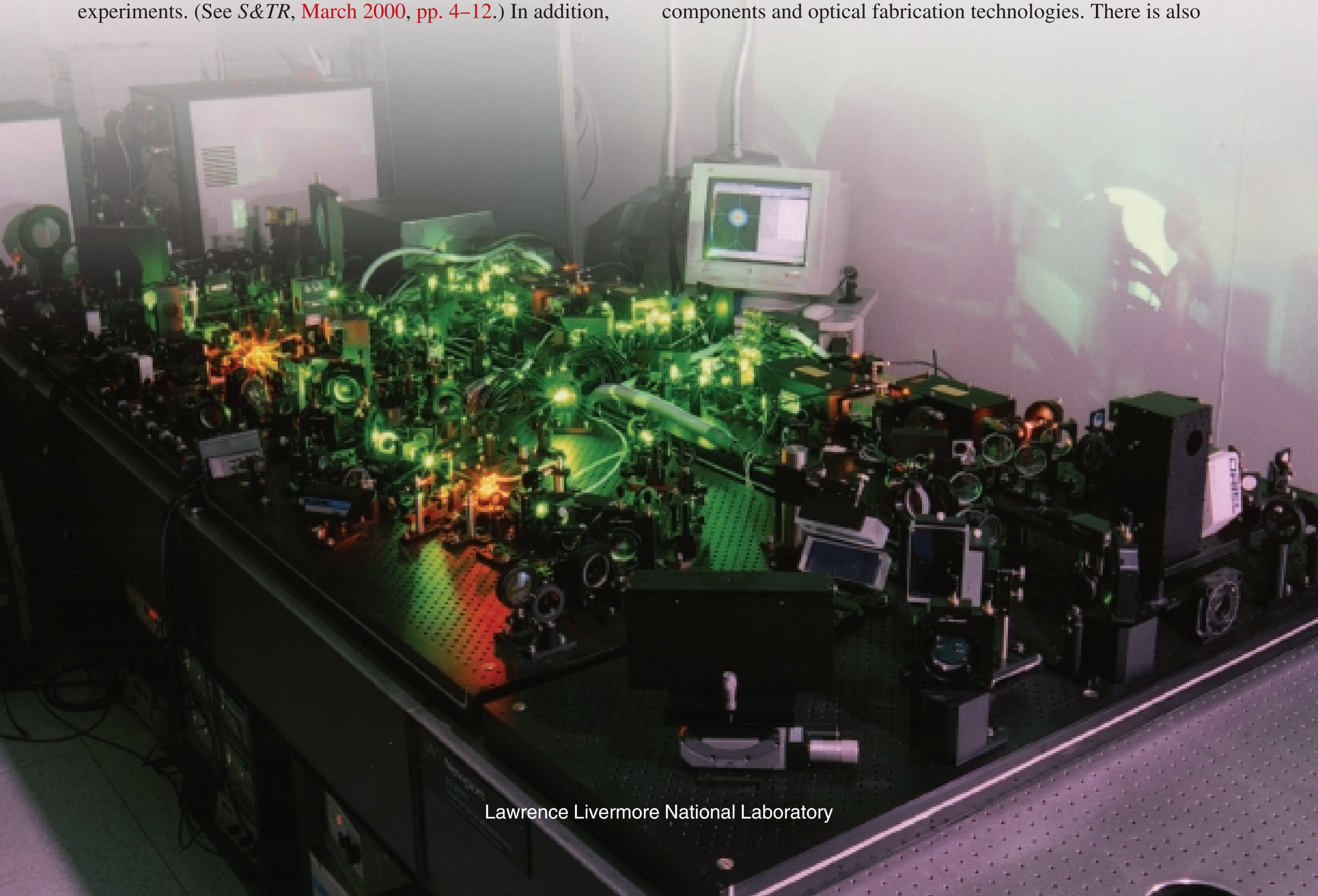
Further Developments in Ultrashort-Pulse Lasers

LIVERMORE continues to push the frontiers of laser science. Researchers have taken the ultrashort pulses of the record-shattering Petawatt laser and found new uses for them. They are also applying a novel technology to create extremely short laser pulses with high average power and high energy to access and investigate extreme-field conditions. The technology improvements will benefit the Stockpile Stewardship Program as well as national defense and manufacturing.

The Petawatt laser operated for three years and routinely produced more than 500-joule laser pulses lasting 500 femtoseconds—less than a trillionth of a second. Experiments with the Petawatt evaluated the fast ignitor method of achieving inertial confinement fusion, generated powerful electrons or x rays for radiography research, and produced short, powerful gamma rays for nuclear physics experiments. (See *S&TR*, March 2000, pp. 4–12.) In addition, the discovery of intense, high-energy, collimated proton beams emitted from the rear surface of Petawatt laser targets has opened the way to new applications such as proton radiography. The Petawatt laser still holds the world's record for the highest peak power ever achieved by a laser.

The Petawatt operated on one of the 10 beam lines of Livermore's Nova laser. When the Nova laser was decommissioned in 1999, the Petawatt went with it. But work on short-pulse lasers by no means stopped, notes physicist Mark Hermann, associate program leader for Livermore's Short-Pulse Lasers, Applications, and Technology program, known as SPLAT, which is a part of the National Ignition Facility (NIF) Programs Directorate. His team of about 30 people is advancing the science of short-pulse lasers and applications, developing new laser components, fielding advanced laser systems, and developing new optical components and optical fabrication technologies. There is also



an active program in short-pulse technology in the Physics and Advanced Technology (PAT) Directorate. This research stems from the need to develop high-temperature plasma sources and accurate plasma probes for high-energy-density materials research.

In SPLAT, a diverse set of challenging projects focused on developing high-average-power, short-pulse lasers for a variety of customers is under way. Current SPLAT-developed laser systems use conventional titanium-doped sapphire (Ti:sapphire) amplifiers, but now the team is developing new chirped-pulse amplifier technologies geared toward high average power. One is a direct, diode-pumped, chirped-pulse amplifier laser crystal that promises efficient, compact, and robust picosecond-pulse laser systems. Another is an optical-parametric chirped-pulse amplification (OPCPA) technique, described in more detail below.

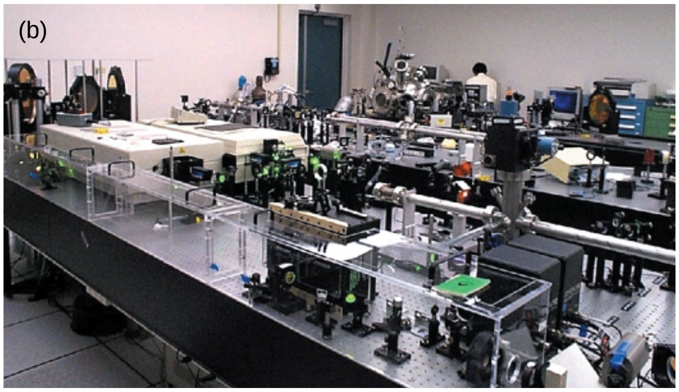
The SPLAT team is using a short-pulse laser to create unique nanocrystals and gain knowledge about the novel properties of nanostructures. This knowledge affects the basic sciences, from solid-state physics to biology. Being able to synthesize nanocrystals of specific size and properties, at an industrial rate, may revolutionize the field of nanotechnology and enable a broad sector of manufacturing, from semiconductors to pharmacology.

The team is collaborating on a project that integrates a short-pulse laser with a Livermore linear accelerator for stockpile stewardship applications. Supporting the team's efforts, Livermore's Diffractive Optics Group is developing new optical technologies and fabricating new optics for petawatt-class lasers around the world, for the National Ignition Facility, and for the National Aeronautics and Space Administration to use in space-based telescopes. The group currently produces the world's largest diffraction gratings.

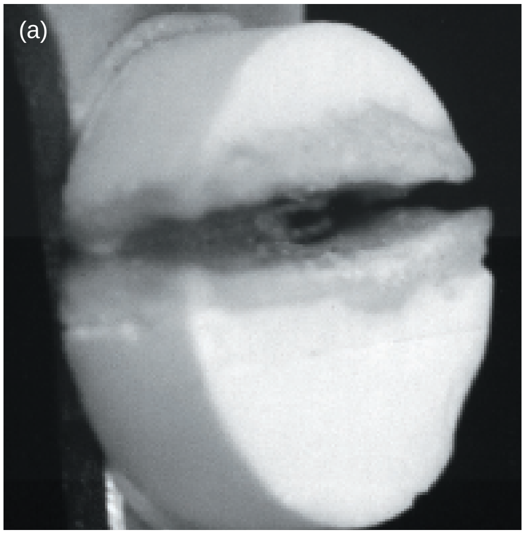
New Path to a Short Pulse

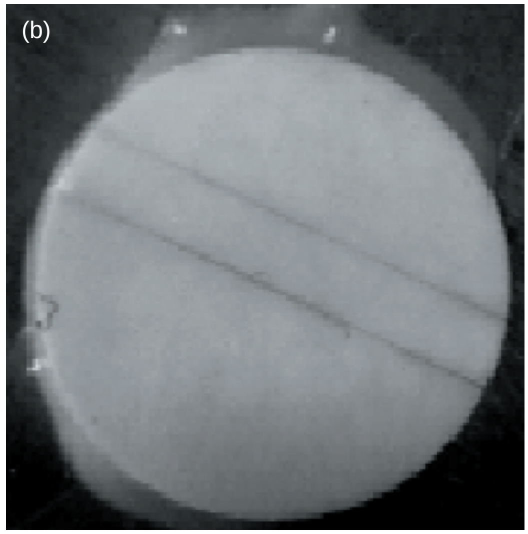
An interesting new development in short-pulse laser technology has been the emergence of OPCPA. Laser-pumped nonlinear crystals made of beta-barium borate (BBO) would replace the Ti:sapphire used in the Petawatt and other conventional lasers as the preamplifier. In a Ti:sapphire regenerative power amplifier, a pulse passes 10 to 100 times through a regenerative cavity, increasing in energy with each pass. By the time it leaves the amplifier, its energy has increased by 10 million, from about 1 nanojoule to approximately 10 millijoules. In contrast, a pair of BBO crystals can produce the same energy gain with a single pass of the light pulse.

With a regenerative amplifier, a tiny bit of energy leaks out with each round trip of the laser pulse. If this leak, or prepulse, is not attenuated, it may cause a preplasma, which changes the coupling of the laser to the target. Many stockpile stewardship experiments use lasers to probe materials essential to nuclear weapons to learn more about their behavior. Keep in mind that the prepulse causes changes that are miniscule by most standards, but when powerful laser pulses of less than a trillionth of a second are used to study detailed physics processes, even minor changes can be significant.



(a) The100-megaelectronvolt linear accelerator and (b) the Falcon ultrashort-pulse laser are being integrated to produce a short-pulse x-ray source. Livermore scientists will use the x rays to probe the dynamics of materials under shock conditions.





(a) A laser with 500-picosecond pulses caused the high explosive LX-16 to burn during cutting. (b) In Livermore's system, the 150-femtosecond laser pulses are so short and fast that they deliver virtually no heat to the area being cut.

Livermore did not invent OPCPA. But, according to Hermann, "Livermore is pushing the frontier of OPCPA technology, combining Livermore's unique expertise in high-beam-quality, high-average-power lasers and nonlinear optics."

A major application for OPCPA will likely be in laser machining, which requires high average power, high beam quality, and ultrashort pulses (about 20 to 1,000 femtoseconds). Unlike other chirped-pulse amplification approaches, OPCPA produces negligible thermal aberrations that in turn cause degradation of the laser beam. Although not yet demonstrated at high average powers, an OPCPA laser should be able to produce hundreds of watts or even kilowatts of average power with high beam quality. In contrast, most conventional Ti:sapphire chirped-pulse lasers, including Livermore's systems, have operated at 20 watts or less. Higher power should translate into faster production and better process control during machining.

Much of the SPLAT program's work is related to stockpile stewardship and improving Livermore's ability to verify the safety and reliability of the nation's aging nuclear weapons stockpile. Before the arrival of OPCPA technology, the team built the Falcon, a 3-terawatt, 35-femtosecond laser facility with a moderate repetition rate, to use as a material probe. A joint team of SPLAT and PAT personnel recently began to integrate the output from Falcon with the electron beam generated by Livermore's 100-megaelectronvolt linear accelerator. Together, the laser and the accelerator will be an advanced light source whose ultrafast and ultrabright pulsed x rays will be used as probes for dynamic studies of solid-state and chemical systems.

Hermann notes that the Falcon and other short-pulse lasers at Livermore may benefit from being upgraded with the OPCPA system. "Controlling and in some cases eliminating the prepulse is desirable," says Hermann. "It means that researchers will be able to control the experimental initial conditions of the laser material dynamics."

Benefits Abound

Emerging technologies for optical-parametric chirped-pulse amplification and diffractive optics will soon find their way into several Livermore lasers, from small high-average-power systems for manufacturing to high-energy systems such as NIF, the 192-beam laser being built to support stockpile stewardship science research. NIF and SPLAT personnel are assessing the potential for adding these technologies to produce short pulses on NIF. Combining ultrashort pulses with the powerful, multimegajoule capacity of NIF would result in a unique system, one that may be able to demonstrate fast ignition for the production of fusion energy, increase NIF's stockpile stewardship capabilities, and investigate new areas of extreme-field science.

—Katie Walter

Key Words: diffraction gratings, Falcon laser, femtosecond laser machining and cutting, high-average-power lasers, nanocrystals, optical-parametric chirped-pulse amplification (OPCPA), Petawatt, ultrashort-pulse lasers.

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